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DETECTION AND MITIGATION OF AGING EFFECTS OF NUCLEAR POWER PLANT COMPONENTS

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Paper

DETECTION AND MITIGATION OF AGING EFFECTS OF NUCLEAR POWER PLANT COMPONENTS

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ABSTRACT

This paper describes the general principles of the methods for timely detection and mitigation of aging effects. These methods include condition monitoring, failure trending, system reliability monitoring, predictive maintenance and scheduled maintenance. In addition, developments of existing detection and mitigation methods needed to improve the capability for effective managing of nuclear power plant aging are discussed.

RÉSUMÉ

Le présent rapport donne les principes généraux des méthodes à utiliser pour déceler et atténuer à temps les effets du vieillissement des composants des centrales nucléaires. Ces méthodes comprennent le contrôle des conditions, les modèles de défaillances, le contrôle de la fiabilité des systèmes, ainsi que la maintenance prédictive et la maintenance prévue. Le rapport traite en outre des développements nécessaires aux méthodes actuelles de détection et d'atténuation pour améliorer l'efficacité du contrôle du vieillissement des centrales nucléaires.

DETECTION AND MITIGATION OF AGING EFFECTS OF NUCLEAR POWER PLANT COMPONENTS

1. Introduction

Aging degradation of nuclear power plant (NPP) components, if not effectively monitored and controlled, may result in the impairment of their performance characteristics leading to a reduction of the reliability of associated station systems (both active and standby systems may be affected).

Effective control of aging degradation of NPP components requires timely detection and mitigation of the degradation. (The term components is used in a broad sense and includes plant structures and systems.) Nuclear utilities have been using different programs or methods to prevent, detect, correct and mitigate failures of NPP components from any cause, including the effects of aging degradation. These methods include testing, surveillance, preventive maintenance programs, significant event reporting systems, periodic reviews of NPP performance, and operational, maintenance and design changes initiated on the basis of detected component failures or deficiencies. They have been under continuous development (based on lessons learned and new knowledge), and overall quite effective in maintaining acceptable operational reliability of NPPs.

In the past, aging was considered just one of many possible causes of component failures, and aging research as well as design, operation, monitoring and maintenance improvements were primarily in response to experienced operational problems or failures. However, in recent years the industry, regulatory and international organizations recognized that as the average age of NPPs increase, a more systematic and proactive approach to NPP aging is needed to ensure continued plant safety. As a result, a number of programs or projects have been initiated by different countries, IAEA, Nuclear Energy Agency of OECD, etc., to understand aging and to utilize existing or develop new methods for managing its effects. Studies of operating experience and specifically of age-related component failures have shown that a majority of aging degradation or failures can be detected by good performance monitoring and preventive maintenance programs. Although no drastic changes are needed, there is a need to review these programs for their effectiveness in detecting and mitigating aging

effects, and where necessary to enhance them by new and improved methods. To be effective, the applied methods must be able to detect and mitigate aging degradation of safety-related components before failures. (In this document, failure is considered to occur when a component is unable to meet its minimum performance requirements.)

This paper describes the general principles of the methods for timely detection and mitigation of aging effects.

2. Performance Monitoring as a Basis for Preventive Maintenance

If allowed, uncontrolled aging degradation of NPP components would increase the corrective (i.e. breakdown) maintenance workload and slowly degrade plant performance in terms of both plant safety and production reliability. To maintain adequate plant performance, plant personnel must be able to monitor and predict component and system performance so that appropriate preventive actions can be done before projected failures. Three means of performance monitoring, namely condition monitoring, failure trending and system reliability monitoring, are discussed below.

2.1 Condition Monitoring

Condition monitoring of components may be defined as a continuous or periodic observation and evaluation of appropriate indicators to assess components' ability to continue to perform their specified functions during a period following the time of observation. The prescribed observations may take the form of measurements or periodic tests or inspections designed to produce consistent, repeatable results, in which current performance or condition is determined. Observed values are then compared with minimum acceptance criteria and with results of the same previous observation on the same component. A determination of present and projected conditions is made utilizing both absolute and relative comparisons of observed indicator values to define when and what maintenance is required.

Ideally, monitoring a single condition indicator would suffice to indicate the functional capability and exact criteria would exist to decide, based on the observed value of the indicator, what action to take at the time of the

observation, i.e., to continue operating without change, to perform maintenance or calibration, to repair the component, or to replace the component. An acceptable indicator for condition monitoring must be a precursor indicator, that is an indicator providing a warning of impending functional degradation that may not yet be apparent. A precursor indicator must therefore have a change which is detectable before component failure.

An illustration of the ideal situation is given in Figure 1 (Ref. 1). The bottom half of the figure shows the time variation of two indicators of a component condition; the top half of the figure displays the time variation of the component functional capability. At the observation time although some component degradation has occured, there is no decrease of the component's functional capability. The "unacceptable indicator", which correlates strongly with the component's functional capability, does not show any change. The component degradation is, however, indicated by the decrease in the value of the "acceptable indicator" which may be some component characteristic such as abnormal voltage, response time or mechanical wear.

Criteria can be established that require maintenance to be performed when condition monitoring parameters deteriorate to a specific level or vary in a specified manner. These criteria should relate to component performance under both normal and accident conditions, and therefore should be established on the basis of operating and equipment qualification experience or laboratory research. In Figure 1, the interval between the moment of observation and the time corresponding to the minimum allowable functional capability is an estimate of the remaining service life of the component if no corrective measures are employed to enhance the life of the component.

Conceptually, a criterion may take the form of a statement such as: When the level of the condition indicator reaches the value A, preventive action B should be taken. For the purpose of illustration, consider an instrument cable, with all its connections, between an alarm in the control room and a pressure transmitter in the containment of a nuclear power plant. Suppose it was established in the instrument cables qualification program that the leakage current in the cable measured at 500 Vdc is an acceptable condition indicator, and if it exceeds 2.0 mA, the pressure transmitter signal may have excessive error should a loss of coolant accident (LOCA) occur one year after the

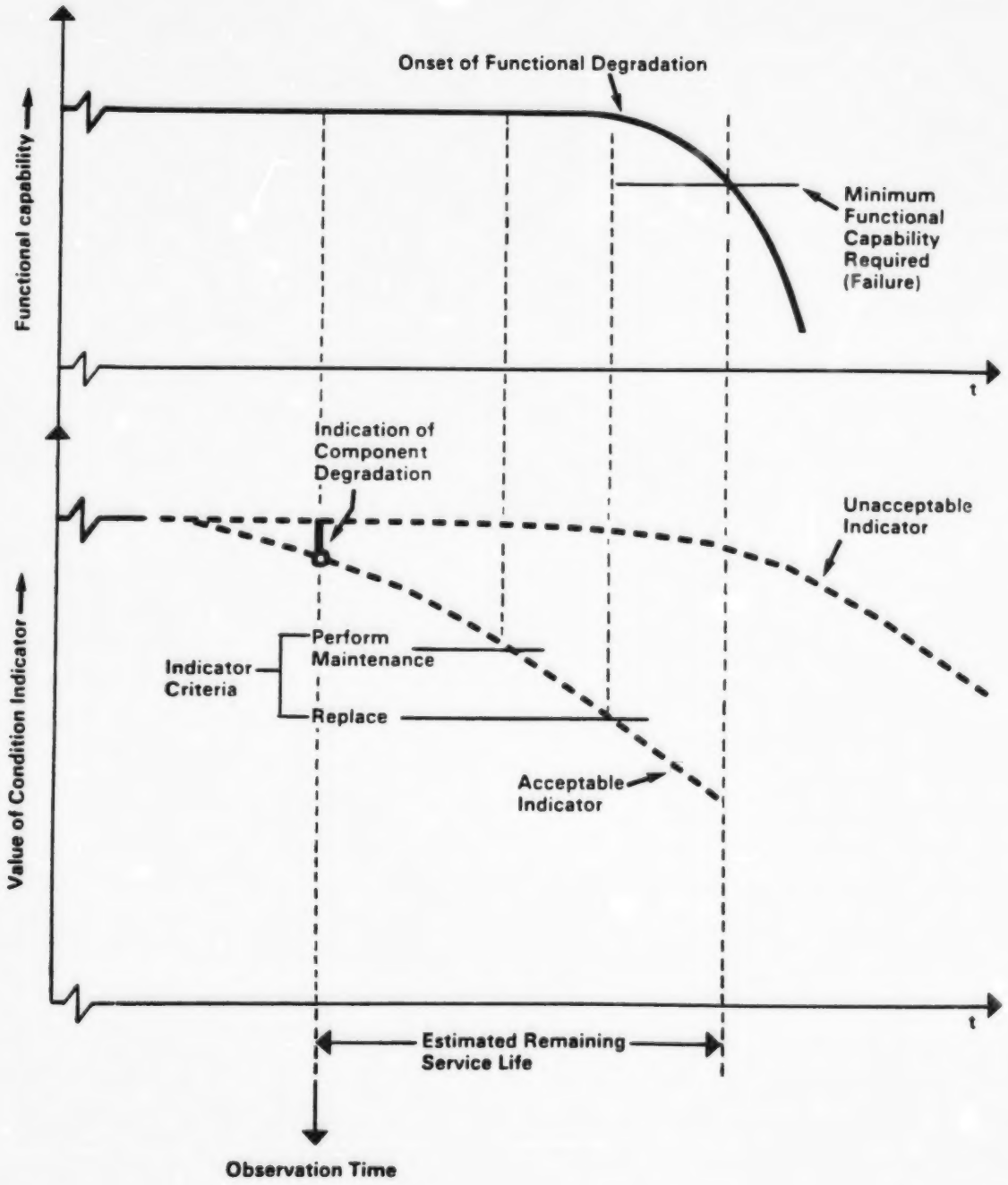

Figure 1: Use of Condition Indicators for Condition Monitoring

observation. The condition monitoring criterion should take the following form: If the leakage current of the cable measured during prescribed periodic inspection exceeds 2.0 mA at 500 Vdc, the corrective action must be taken within a year to identify and correct the cause of the leakage current (the cable must be replaced if no defects are found or the repair of the identified defects does not remedy the situation). Since the rate of degradation is an important considertion for maintaining adequate functional capability, the timing of the corrective action should take into account the rate of change of the leakage current. The criterion may therefore include a requirement to increase the frequency of the leakage current measurements before the cable degradation is remedied.

The effect of maintenance on the functional capability of a component and its remaining estimated service life is shown in Figure 2 (Ref. 1). With each maintenance, the component is normally upgraded and as a result the condition indicator value moves up, the functional capability curve moves to the right, and the residual service life is extended until a point is reached at which it becomes more cost- effective to replace the component. Of course, the replacement should be done sufficiently in advance of the expected component failure.

In practice, the challenge is to identify indicators suitable for condition monitoring of different types of NPP components and the predictive criteria to decide what and when preventive action is required. A number of different condition monitoring techniques are being used and others are being developed on the basis of operating experience (including root-cause analysis of failures and correlation of observed indications with failure rate) and research and development (R&D). The techniques must be applied so as to ensure their repeatability which is prerequisite for condition and performance trending. This means that test conditions, such as process conditions, system valve lineup, test equipment accuracy and test personnel qualification, must be consistent from one test to another. This should be reflected in the condition monitoring program procedures.

Examples of some of the common indicators of degradation include items such as voltages, currents, response times, setpoint drift and contact resistance change from routine tests and calibrations of instrumentation and control components.

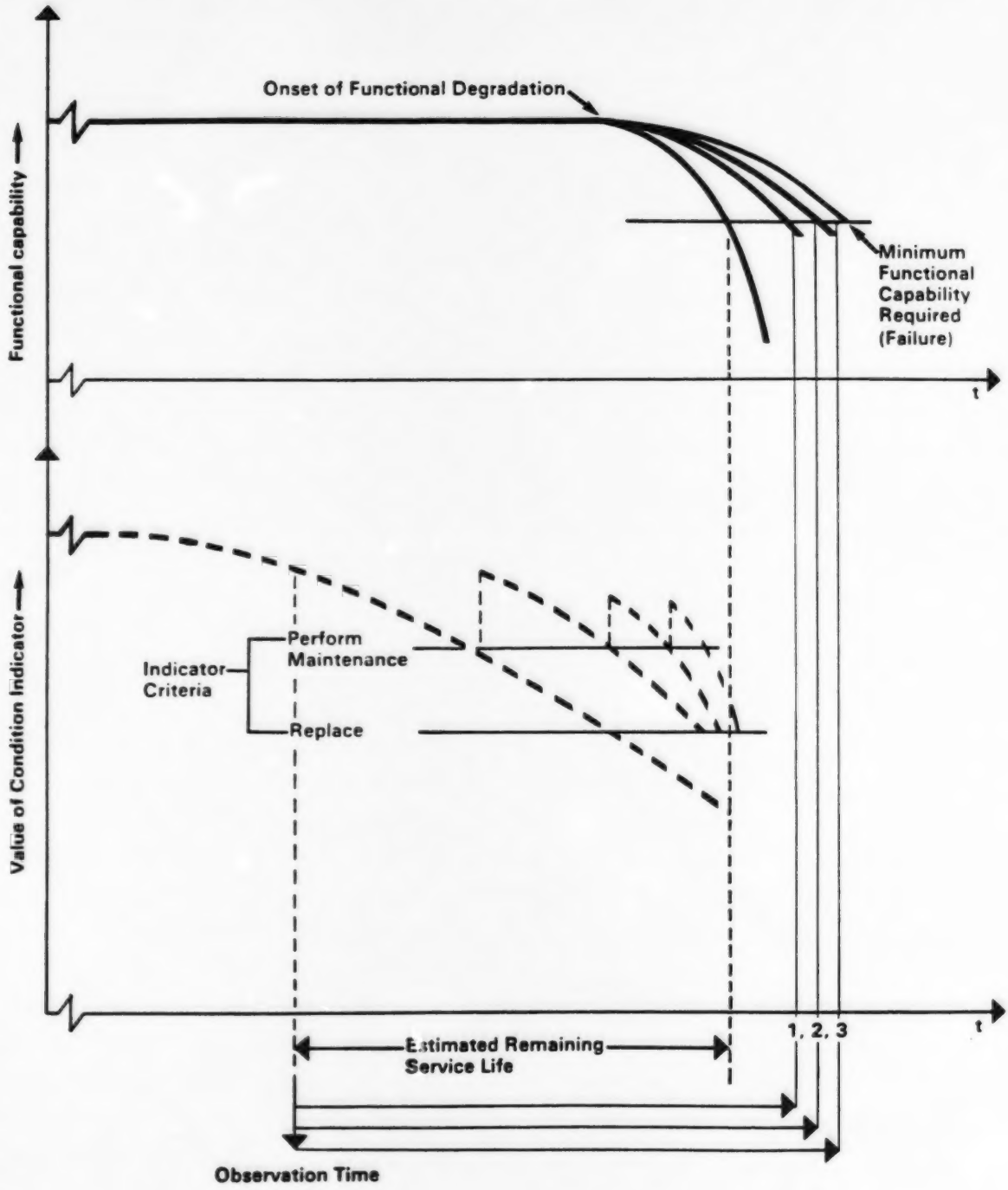

Figure 2: Effects of Preventive Maintenance on Functional Capability and Remaining Estimated Service Life

Also included are mechanical wear, corrosion, binding or bent parts from visual inspections, or abnormal readings from comparisons of like process/operation parameters. Vibration monitoring of rotating equipment, motor current monitoring of motor operated valves and nondestructive examination techniques for pressure retaining components are three examples of condition monitoring methods which are briefly described below.

Examples of Condition Monitoring Methods

Vibration monitoring - Vibrations have long been known as indicators of rotating equipment condition. Long before the appearance of electronic vibration monitoring equipment, maintenance personnel were monitoring machine vibration by touching and listening to the machine. Modern piezoelectric accelerometers and velocity probes along with computer-based data acquisition and analysis equipment have brought a step change in the capabilities of vibration monitors. Detailed processing and analysis of the vibration spectra now allow automated diagnosis of machine problems. Since power plants have large numbers of rotating equipment, vibration monitoring has found widespread application (e.g. Ref. 2) as a condition monitoring technique.

Monitoring of motor operated valves - The motor current during a valve stroke is a very useful diagnostic parameter for detecting and trending aging degradation of motor operated valves (MOVs), (Ref. 3). From the standpoint of diagnostics, the motor is acting as a transducer, converting the drive train mechanical loads and their variations with time into variations in voltage across the windings. The resulting net current flow in the motor power leads then reflects the characteristics of the motor load. Changes over time reflect MOV degradations which appear as load changes.

Motor current can be measured remotely and non-obtrusively during plant operation, since no leads need to be lifted to attach a clamp-on current sensor. Reading and recording the motor current can be carried out rapidly, either manually or automatically. To utilize this technique for determining operational readiness, a data base is being developed, by Oak Ridge National Laboratory, to correlate diagnostic parameters with MOV degradation.

It is anticipated that this technique will find application in the diagnostic monitoring of degradation in other motor driven components used in nuclear power plant safety systems, as well as in many non-nuclear applications.

A commercially available system for the assessment of motor-operator and valve functional performance is the MOVATS system (Ref. 4). The assessment is based on the measurements of stem thrust, motor-running current, bus voltage plus limit switch, torque switch and bypass switch activation positions within the valve stroke.

Nondestructive examination (NDE) techniques - NDE of pressure retaining components plays an important role in assuring their structural integrity. Procedures and detailed NDE techniques for periodic inspection are established by the utilities in accordance with various codes and regulatory requirements. NDE serves not only to detect component degradation, but also provides vital information about the materials, enabling appropriate corrective measures to be taken to prevent failure. NDE techniques include eddy current methods, ultrasonic methods, radiography, magnetic particle testing, dye penetrant testing and visual inspections.

2.2 Failure Trending

Another approach to component performance monitoring is to evaluate the statistical pattern of component failures over a period of time.

The failure rate of components as a function of time is given by the well-known bathtub curve, shown in Figure 3. In their early life, which is called infant-mortality (or burn-in) period, components may experience a high failure rate. During their useful life, the failure rate of components is characterized by random failures, and the failure rate is approximately constant. Components experience an increasing failure rate in the late part of their life, which is characteristic of the wearout period. As shown in Figure 3, electrical components generally experience a more constant failure rate in the useful life period than do mechanical components. The initial high failure rate of components can be eliminated in many cases before a plant is put into service by burn-in or commissioning testing. An effective performance monitoring program can help to ensure that prompt corrective action is taken when the wearout region is reached.

The failure pattern discussed here is statistical in nature, i.e., it indicates when the component will have higher probability of failure. If significant statistical data are available for such failure predictions, then surveillance, preventive maintenance, or replacement can be scheduled more effectively on the basis of failure trends. If the failure pattern of a device shows that the probability of failure increases significantly after a certain life service, scheduled replacement of the equipment, rather than replacement based on condition monitoring results, may be used.

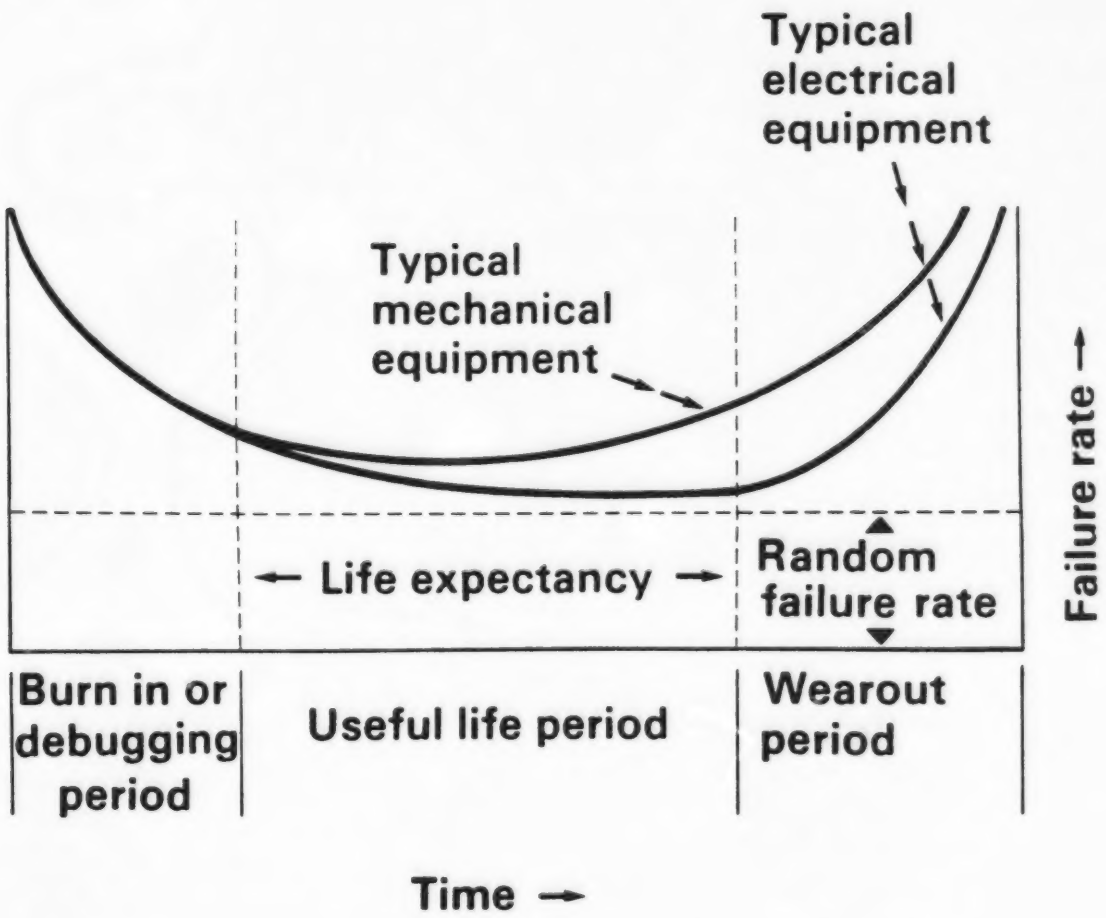

Figure 3: Time Dependence of Failure Rate

Failure trending requires a systematic collection and analysis of failure data. Equipment deficiencies must be recorded in a specified, systematic manner to allow determination of the severity of failures, failure modes and the root cause/s of failures. Trends of failures and their causes may be then monitored. The component failure rate monitoring program should periodically evaluate component failure rates and compare them against component lifetime experience and generic failure rate data. Because of the multiplicity of NPP components, this then may allow early recognition of increasing failure rate and timely elimination of developing weak spots before the failure of a system.

The failure rate pattern discussed above relates to normal service conditions. Establishment of frequency of inspection and maintenance must include consideration of the effect of postulated design basis event (DBE) service stresses. Figure 4 shows the effect of normal and accident service stresses on accumulated deterioration (Ref. 1). The DBE service conditions will cause stresses that are usually more severe that normal service stresses which include transients from process system upsets. Care must be taken in the development of inspection and maintenance intervals that sufficient capability to withstand DBE conditions remains throughout each interval. The combined effect of normal and possible DBE-related deterioration must be such that equipment is not allowed to significantly enter the wearout region where failure rates become exponential and the bulk of the equipment would be expected to fail. However, very few data exist relating the effect of DBE service conditions to changes in failure rate. Therefore, to use failure rate data as a basis of determining inspection and maintenance intervals, considerable conservatism must be incorporated to account for the effect of postulated DBE service conditions.

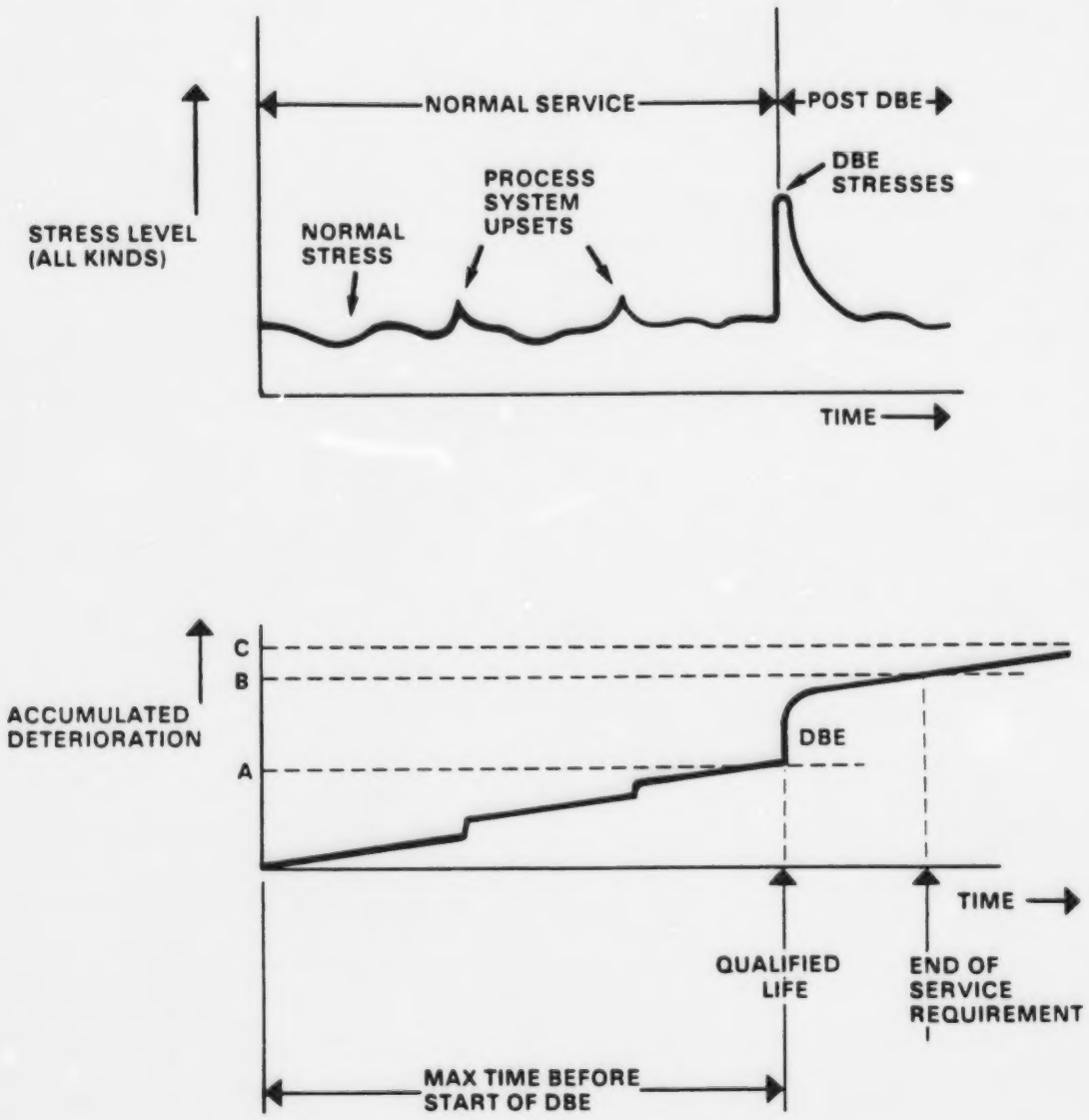

Figure 4: Accumulated Deterioration Related to Service and Design Basis Event Stresses (seismic, LOCA, MSLB)
A = maximum in-service deterioration allowed
B = maximum deterioration expected after DBE
C = end of life/component failure
B - C = performance/safety margin
MSLB = main steam line break

2.3 System Reliability Monitoring

System performance can be monitored using reliability methodology. This methodology permits a quantitative assessment of the system performance against performance standards or targets which can be established on the basis of experience, regulatory requirements, international recommendations and other considerations. If a performance target is exceeded, the cause (e.g. aging degradation) as well as appropriate follow-up and corrective actions are identified to achieve and maintain a satisfactory level of performance. The corrective actions may include changes to testing, inspection and monitoring practices (e.g. frequency and parameters monitored), review and possible changes of design, operation and maintenance, and R&D work. Priorities for corrective actions should be set on the basis of the importance of the component in meeting the performance target of the system. The impact of the corrective actions on the system performance should result in an improvement of the reliability parameters followed by the reliability monitoring program. Main elements of the process, outlined above, are depicted in Figure 5 (Ref. 5).

A development of the system reliability monitoring program involves the following steps:

- setting of appropriate reliability targets

  (For example, Canadian target for shutdown, emergency core cooling (ECC) and containment systems requires the unavailability of each system to be less than 10^{-3} a/a.)

- deriving system reliability models

  (The level of detail of the models should reflect the expected quantity of failure data. For example, for the standby safety systems function block models may be used because of a limited amount of failure data collected due to the inherent reliability of each component.)

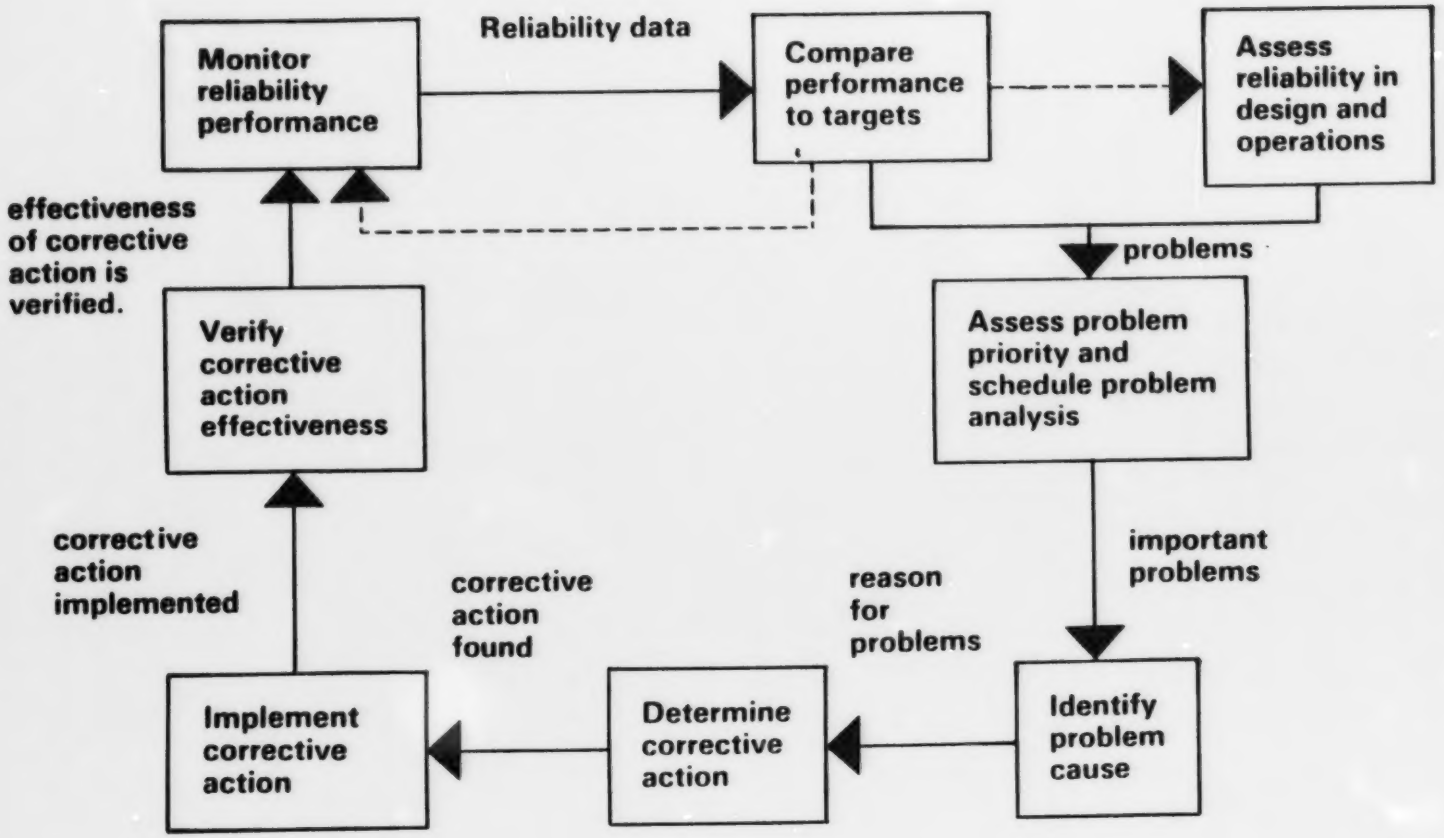

Figure 5: System Reliability Monitoring Process

- developing the test and inspection program to provide confidence that standby systems would work when called upon

  (Components to be inspected, functions to be tested and the types and frequency of tests/inspections is determined using the system reliability target, reliability model, component failure rate data, the expected aging processes and operating characteristics.)

- performing and recording of scheduled tests and inspections

- analyzing test and inspection results to determine duration, severity and causes of observed failures

- assessing periodically system operational reliability (i.e. performance) using system reliability models, the test and failure data

- comparing past and predicted future system performance with reliability targets and where applicable identifying major contributors to system unavailability or unreliability

- ensuring that appropriate follow-up and corrective actions are taken to remedy any system reliability problems

- monitoring the expected impact of corrective actions on the system performance

An example of the system reliability monitoring program is the program used by Ontario Hydro, a Canadian utility with experience of over 170 reactor-years of operation. (Ref. 6). The basic objective of the program is to determine, on the basis of operating experience gathered on a particular system, whether the system's performance over the past year was acceptable and will continue to be so in the future. The program has been applied primarily to monitoring reliability of so called special safety systems, that is shutdown systems, ECC and containment systems. However, the methods are generally applicable to any plant system where additional insight into its performance is desired.

Because special safety systems are carefully designed and maintained, component failures are relatively infrequent. This fact, coupled with the built-in redundancy, makes total system failure highly improbable. Although such features contribute to high reliability, they also make meaningful performance assessments difficult because of the limited failure data.

Despite the data limitations, considerable insight can be gained by analyzing the operational data. The Ontario Hydro program involves tracking of a number of reliability parameters because no single parameter can provide sufficient information to adequately judge reliability performance of a system in operation. The parameters tracked to assess performance of special safety systems are:

- system inoperability
- observed system unavailability
- derived system unavailability
- expected system unavailability

System inoperability is the time fraction of the past year when a system was fully incapable of providing protection for the events with which it was designed to cope. This parameter is determined directly form observation. It does not include marginal failures to meet the design intent of the system and is therefore a nonconservative measure of system performance.

Observed system unavailability is the time fraction of the past year when the system was unable to satisfy fully all design requirements. In other words, the system is deemed unavailable when it fails to provide required protection for one or more of the design basis events. (It follows, that the system's performance may be acceptable for all but one of the postulated events.) This parameter is again determined directly from observation, and includes all faults which resulted in a system inoperability and all other faults which reduced the system's funcional capability below any of its design requirements. While the observed system unavailability provides a conservative measure of the actual system performance, it is susceptible to large statistical fluctuations from year to year. When used in conjunction with "system inoperability", it is useful in distinguishing between major system faults which definitely affect

public risk, and faults that may only marginally reduce the system's functional capability below the design requirements derived from the plant safety analysis.

Derived system unavailability is a parameter calculated using a system reliability model and the system failure data from the past year. All unsafe faults that occurred over the past year are included and component unavailabilities are calculated by using an estimate of average future fault durations. This parameter provides more information than "observed system unavailability" on the contribution of individual component failures to overall system performance. It also provides an indication of the statistical significance of the value of the observed system unavailability in a particular year: for example, if an observed unavailability is much less than a derived unavailability it indicates a fortuitous situation that should not be expected to continue in the long term.

Expected system unavailability is calculated using the same reliability model as derived system unavailability and all relevant fault data collected over the life of the station. Where few or no component failures have been observed, a 50% confidence Chi-squared estimate of failure rate is used to provide an estimate of component performance. After a few years, this parameter provides a statistically valid upper limit estimate of long-term average system performance. Because it uses all relevant experience, it does eventually become relatively insensitive to sudden changes in the performance of equipment, but such changes are detected by other means (e.g., derived system unavailability).

A further check on the performance of special safety systems is carried out via the component failure rate trend monitoring program. Each special safety system component is monitored on an annual basis. Its annual performance is checked against its own lifetime experience in addition to the standard generic failure rate data banks such as NPRDS. In this way, deteriorating component performance can be recognized before it impacts on overall safety system performance.

The reliability parameters used by Ontario Hydro have proven useful in interpreting data to better understand the actual reliability performance of special safety systems. Their use, since 1962, facilitated identification of the problems which caused systems not to meet their reliability targets. The

program also helped in understanding the significance of the problems and in setting priorities for corrective actions. Examples of aging degradation problems identified and corrected with the aid of the program include failures of ECC injection valves caused by the degradation of the grease used to lubricate limit switch assemblies of the valves, and failures of dousing system solenoid valves caused by the degradation of elastomeric internals in high temperature environment. Besides drawing attention to hardware problems, the system reliability monitoring program has also helped to optimize testing program and the operating and maintenance practices affecting safety system reliability performance.

3. Preventive Maintenance as a Means of Managing of Aging Effects

Effective preventive maintenance (PM) programs are essential for ensuring acceptable operational reliability throughout the service life of nuclear power plants. This section does not attempt to describe a PM program, but aims only to highlight those program developments which are important to managing of aging effects.

The role of PM to detect and mitigate component degradation before failure is accomplished through two kinds of preventive maintenance, scheduled maintenance and predictive maintenance.

Safety related components should be covered either by predictive or scheduled maintenance programs, which means that their maintenance would be based either on some type of performance or condition monitoring, or on a call-up (time-directed) system.

To ensure effectiveness of PM programs, they should be periodically reviewed and modified on the basis of operating experience. It has been shown (Ref. 7.6) that the reliability-centered maintenance (RCM) methodology, developed in the aviation industry for a wide body jet aircraft, is an effective tool for the review and development of PM programs for nuclear plant systems. RCM considers the contribution of each component to the functioning of the selected system, and using a logic tree analysis identifies practical and effective PM tasks.

The following subsections deal with the topics of predictive maintenance and scheduled maintenance, and also give further information on RCM application.

3.1 Predictive Maintenance

Predictive maintenance, or condition-directed maintenance, is a maintenance initiated on the basis of observed present and projected future component conditions. The timing and the kind of maintenance work is determined utilizing trends of both absolute and relative comparisons of component conditions.

Maintenance decision methodology requires reliable techniques for failure or wear out predictions. The objective is to predict component performance so that maintenance or repairs can be planned and completed before the projected failure occurs. RCM approach can be used to develop appropriate plant specific PM procedures and plans.

RCM is a systematic method for developing or reviewing PM programs. In brief, RCM is a systematic consideration of system/subsystem functions, the way functions can fail, and the safety and economic importance associated with these functional failures. Potential PM tasks are then considered and those tasks which can reduce failure probability and are economically viable are selected.

The process starts with the collection of all pertinent design, operating and maintenance information for a selected system. The system, its functions, boundaries and interfaces are described, and its functional failures (i.e. how it can fail) identified. The review of operating and maintenance experience is performed to determine actual failure modes, their root causes and effects (i.e. severities) for each functionally significant item. Condition indicators able to indicate component degradation before failure (i.e. precursor indicators) are then determined (where possible) for the most important failure modes identified in the review of experience. For the condition indicators to be monitored, standards or minimum acceptance criteria (based on the system functional requirements) must be determined, so that a performance monitoring program which measures actual component conditions at appropriate time intervals can be designed. Finally, applicable and effective PM tasks to mitigate component degradation before failure are identified.

The outcome of the RCM based review of a PM program for NPP safety related systems will be a mixture of predictive maintenance and scheduled maintenance or component replacement. For standby safety systems the principal strategy will be the predictive maintenance based on some type of condition monitoring.

To implement the predictive maintenance program, it is necessary to store and analyze relevant data and report trends so that the extent of degradation can be determined and a decision on the kind and timing of preventive action made. The large amounts of relevant data to be processed (i.e. condition monitoring data, maintenance history data, operating data, and pertinent acceptance criteria), require use of computerized data processing. Experience will show which condition monitoring and data analysis techniques are appropriate for failure prediction. A number of iterations may be required to optimize a PM program.

3.2 Scheduled Maintenance

Although the trend in preventive maintenance is towards more predictive maintenance, some equipment is and will continue to be covered by scheduled maintenance. The reason may be a lack of practical condition monitoring method or the effectiveness of the scheduled maintenance for given equipment.

Initially, the scope and timing of scheduled maintenance is based on manufacturers' recommendations, warranty and regulatory requirements, and plant staff experience. Scheduled maintenance programs should be periodically reviewed and optimized on the basis of operating experience to reduce corrective maintenance and thus improve component reliability. An optimization approach should incorporate analysis and engineering assessment of the plant operating and maintenance history to determine component failure modes and causes, the interval between failures, and when in plant life the failures occurred. Based on this information it is possible to determine which scheduled maintenance tasks are effective and when they should be performed. (To repeat, the term components is used in a broad sense and includes plant structures and systems.)

An example of the scheduled maintenance optimization strategy, developed by Advanced Technology Engineering Systems Inc. (Ref. 8), is outlined below, and the basic steps of the optimization process are shown diagramatically in Figure 6.

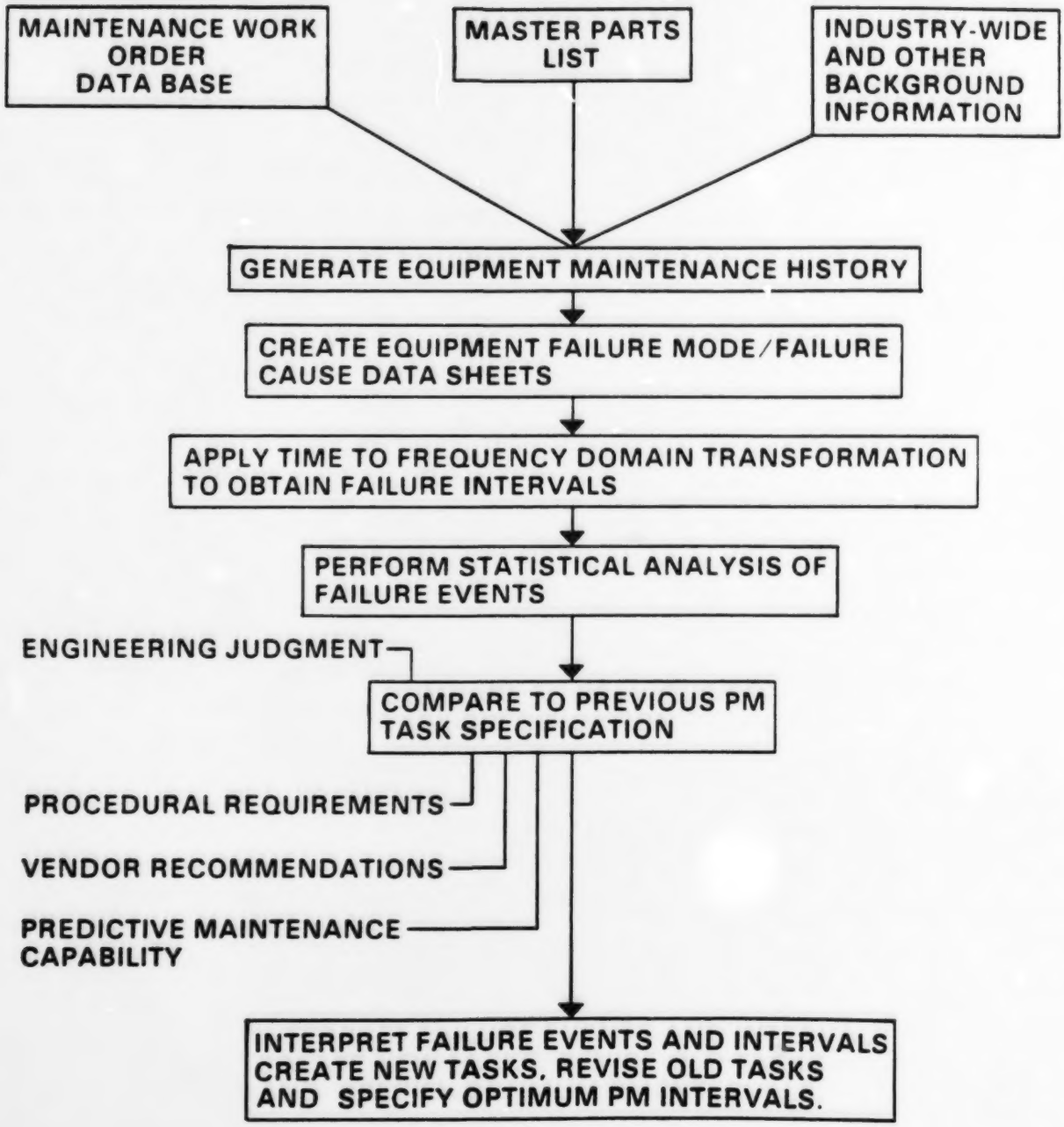
MAINTENANCE WORK ORDER DATA BASE
MASTER PARTS LIST
INDUSTRY-WIDE AND OTHER BACKGROUND INFORMATION
GENERATE EQUIPMENT MAINTENANCE HISTORY
CREATE EQUIPMENT FAILURE MODE/FAILURE CAUSE DATA SHEETS
APPLY TIME TO FREQUENCY DOMAIN TRANSFORMATION TO OBTAIN FAILURE INTERVALS
PERFORM STATISTICAL ANALYSIS OF FAILURE EVENTS
ENGINEERING JUDGMENT
COMPARE TO PREVIOUS PM TASK SPECIFICATION
PROCEDURAL REQUIREMENTS
VENDOR RECOMMENDATIONS
PREDICTIVE MAINTENANCE CAPABILITY
INTERPRET FAILURE EVENTS AND INTERVALS CREATE NEW TASKS, REVISE OLD TASKS AND SPECIFY OPTIMUM PM INTERVALS.

Figure 6: Scheduled Maintenance Optimization Process

The process starts with the generation of an equipment maintenance history package (including existing PM tasks, relevant drawings, etc.) for each equipment type on a system by system basis. The packages are reviewed to determine which equipment have significant failure histories. For each such equipment, significant failure modes and causes are determined and entered into annual data sheets (starting with year 1 of commercial operation). The data are then input to the time-series analysis (TSA) computer program whose results show the frequency of equipment failures. In addition to TSA, the data is statistically analyzed to identify if any relationships exist between apparently unrelated variables, and if there is any cause-effect relationship among system failures. The results of the TSA and statistical analyses are summarized and reviewed against the operating experience analyses results and the existing PM tasks to recommend changes to both PM tasks and PM intervals. In doing this, interviews with the plant staff are important to clarify non-cyclical events which are not necessarily preventable by maintenance.

Applications of the above described approach for optimizing scheduled maintenance have resulted in the reduction of equipment failures due to time-related degradation through effective PM as well as the correction of identified design and operational problems.

4. Developments Needed in the Areas of Detection and Mitigation of Aging Effects

As discussed earlier in this chapter, managing the effects of aging degradation requires effective methods to monitor and predict component and system performance so that appropriate preventive actions can be taken before projected failures of safety related components will occur. General principles and examples of methods for timely detection and mitigation of aging effects have been given in the preceding sections. The question is: What needs to be done to improve our capability in these areas?

In the area of detection of aging effects, most of the current testing and surveillance programs adequately verify availability of NPP components at the time of observation, yet may not provide sufficient information for trending performance or failure prediction. Improvement of the effectiveness in mitigating aging degradation of various plant components depends to a large extent, on better understanding of pertinent aging mechanisms acting on various component materials under different service conditions. Thus, in general, there is a need to review existing performance monitoring and maintenance methods and practices for their effectiveness in detecting and mitigating aging effects of safety significant NPP components, to identify specific needs for improvement, and resolve them by R&D and design or operation improvements, as appropriate. This general need is being addressed by a variety of studies and programs, some of which are outlined in the following chapter.

The engineering studies are being performed on a component-type basis for the components which have been identified as having an aging-related impact on the reliability of safety-related systems. These studies aim to identify and understand significant modes of component degradation, suitable condition indicators, preferred performance monitoring and maintenance methods and practices, and minimum acceptance criteria. Other research is currently being conducted to refine reliability approaches, risk prioritization schemes, statistical indicators to trend system performance and direct, risk-based predictive indicators of plant performance. Additional studies aim to develop technically acceptable methods for predicting remaining service life based on operating and maintenance history.

The area of condition monitoring development deserves further elaboration.

Typically, there are thousands of safety related components at a nuclear power plant. Although, in principle desirable, condition monitoring of all of these components may not be the necessary and most effective approach to managing of aging effects. Therefore, guidelines for condition monitoring, as well as

guidelines to develop realistic and quantitative criteria for surveillance and maintenance, should be established. The guidelines should provide, for specific components, the parameters most indicative of age related degradation; criteria for using condition monitoring data to make decisions concerning the type and timing of corrective maintenance or replacement; and practical methods for condition monitoring. The guidelines should also indicate the sample size of a population of similar components that should be monitored. Further, the guidelines should recommend the actions to be taken for other components within the population if a certain number of components being monitored degrade to an unacceptable level. For example, if a certain number of power cables are being monitored and show signs of unacceptable insulation degradation, then direction should be provided for testing and maintenance of the unmonitored cables that are operating under a similar environment.

Broader development of a condition monitoring program is, in general, hampered by inadequate understanding of the degradation mechanisms. This, in turn, makes it difficult to identify or develop appropriate condition indicators and monitoring methods. In addition, at present, there is not an adequate correlation between the measurable condition indicators (aging parameters) and the future functional capability during normal and DBE conditions for many types of components. Therefore, repair or replacement decisions are mostly based on experience and engineering judgement rather than predetermined standards or criteria. In this context, it follows that much can be done to enhance our capability for effective managing of aging degradation.

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